Louisiana State Univ
NGL-19-001-068
N70-19865
NASA CR-102462

UTILIZATION OF LIQUID NITROGEN FOR REFRIGERATED

STORAGE OF SHRIMP

SUMMARY

A refrigeration system utilizing liquid nitrogen as the refrigerant was designed, fabricated, and then installed aboard a boat which was outfitted for shrimping in Gulf Coast areas. Shrimp were then caught, processed and stored in an on-board refrigeration box which was designed as a receptacle for the freshly caught shrimp. Liquid nitrogen was introduced into the box in controlled amounts which were sufficient to maintain the temperature of the shrimp between 28°-32°F.

Temperatures of the interior of the box and of the shrimp were monitored and recorded. Shrimp which were stored in ice for the same period of time served as the control. Comparison studies were made between the control and the liquid nitrogen stored shrimp using standard plate count, total coliforms, fecal _Escherichia coli_, and coagulase positive _Staphylococcus aureus_ as criteria for indication of spoilage and contamination.

The data which were collected during the test period demonstrated the superiority of liquid nitrogen storage over conventional ice storage. With the liquid nitrogen system, temperature of the shrimp was maintained at a uniform level, and microbial decomposition of the shrimp was retarded when compared with ice storage.

INTRODUCTION

There has been a recent intensification of inspections by the United States Food and Drug Administration of shrimp catches which has resulted in an increased number of seizures. High bacterial counts, brought about by antiquated refrigeration techniques, have resulted in many millions of dollars worth of shrimp being rejected by the F.D.A., and this has posed a serious economic threat to the industry.

Shrimp trawlers ordinarily fill their holds with ice purchased at dockside, and store it in holds until it is needed. However, this poses problems from both the economic and sanitation standpoints. Ice is expensive to buy and haul. Because of the weight and bulk of ice, the vessel must, of necessity, be much larger, and, therefore, more expensive to operate than would be the case if ice were not required at all. The cost of ice represents a rather large investment to the shrimper, and this is a fixed cost to him regardless of the size of his catch. Larger trawlers sometimes replace ice storage with conventional refrigeration systems. This too, involves considerable expense with regard to installation and operating costs, as well as the cost of the space taken up by such a system.

It is indeed unfortunate that ice storage has remained so prevalent in the shrimping industry, since it has proven to be conducive to poor quality shrimp when not utilized correctly. According to Fieger (1), the shrimp are placed in bins in the hold of the vessel. The usual practice is to place alternate layers of ice four to six inches in thickness, and shrimp two to four inches in thickness. Except for adding ice as needed at the sides and front of the bins, the cargo is not disturbed until unloaded at the receiving house. In case excessive melting of ice occurs, the shrimp are removed from the bin and re-iced as described above.

This method of storing shrimp on board trawlers, although convenient from the point of view of the crew, has several inherent disadvantages. The water from the upper layers of melting ice percolating down through the mass carries bacteria from these layers which are added to the bacterial load of the lower layers. Due to the weight of the ice on the shrimp, considerable crushing of shrimp in the lower layers occurs. This crushing, in addition to the high bacterial count, hastens decomposition and spoilage of the shrimp (2). On arrival at the docks the shrimp are unloaded, after having been stored on the trawler for several days under these conditions, and are often in preliminary stages of decomposition.

It was the objective of this investigation to develop a refrigeration system which would overcome the previously mentioned economic and sanitation shortcomings of ice storage and conventional refrigeration, but which was simple to operate and maintain. Such a system utilizing liquid nitrogen (LN_2) as the refrigerant was chosed due to the following advantages:

1. LN_2 has increased greatly in availability and has consequently decreased in cost to its present level of approximately $40/ton.

2. LN_2 has a temperature of 196°C. (-320°F.) permitting the design of an unusually compact refrigeration system.

3. If no shrimp are caught, the system is not put into operation, and no refrigerant is used except for the negligible amount which may be lost from the tank.

4. Neither LN_2 nor gaseous nitrogen is flammable or explosive.

5. Upon vaporization, the gaseous nitrogen replaces the air surrounding the shrimp, and retards the growth of aerobic microorganisms, as well as preventing any oxidative reactions which are common in shrimp.

6. The system contained only two moving parts, i.e., an electrically operated solenoid valve, and pneumatically actuated microswitch in the temperature sensing probe.

7. By changing the setting of the temperature controller to a lower reading, this system could be utilized for flash freezing and/or frozen storage of fish and shellfish.

EXPERIMENTAL

The physical and operational characteristics of liquid nitrogen for use in a refrigeration system were investigated (Table 1). A refrigeration box was designed within the space limitations imposed by the size of the 26 foot J-boat supplied by the General Electric Company located at the NASA Mississippi Test Facility, Bay St. Louis, Mississippi, where this investigation was conducted. It was found that a box of dimensions 28"x20"x28" (lxwxh) was adequate to refrigerate 100-150 lbs. shrimp, and, at the same time fit into the limited space aboard the vessel. The box was constructed of 1/4 in. sheet aluminum, and was insulated with 2 in. thick styrofoam insulation which was protected on the outside by a plasticized fabric. A cover for the box was also constructed from the same materials (Figures 1 and 2).

Due to the extremely low temperature of the refrigerant as delivered to the box, stainless steel 1/4 in. tubing was utilized for all refrigerant carrying lines. The line which was within the box itself, incorporated two outlet jets 3/16 in. in diameter, and this line was attached to the sides of the box 3 in. from the top. The inlet of this line was connected to a 12 V.D.C. powered solenoid valve which was, in turn, attached to a 1/4 in. insulated stainless steel line. This line extended 7 feet to its connection at the LN_2 tank. The length of the external line was dictated by the space availability aboard the boat. A pressure relief valve was installed at the outlet of the LN_2 tank, and prevented the line pressure from exceeding 95 psi.

The addition of a 16 ft. shrimp trawl and associated boards completed the outfitting of the shrimping vessel.

TABLE 1

PHYSICAL PROPERTIES OF LIQUID NITROGEN

Boiling point, 1 atm, °F.	320.54
Latent heat of vaporization at boiling point Btu/lb.	86.00
Sensible heat (gas to 30°F.) Btu/lb.	87.50
Total heat to 30°F., Btu/lb.	173.50
Liquid density at boiling point, lb./cu. ft.	50.44
Gas density at 0°C. 1 atm, lb./cu. ft.	0.08
Specific volume, standard conditions, cu. ft./lb.	13.80
Specific heat ratio (K) at 70°F. 1 atm., K - Cp/Cv	1.40
Specific heat, const. pressure at 70°F.	0.25
Specific heat, const. volume at 70°F.	0.18
Molecular weight	20.02
Color, odor	none

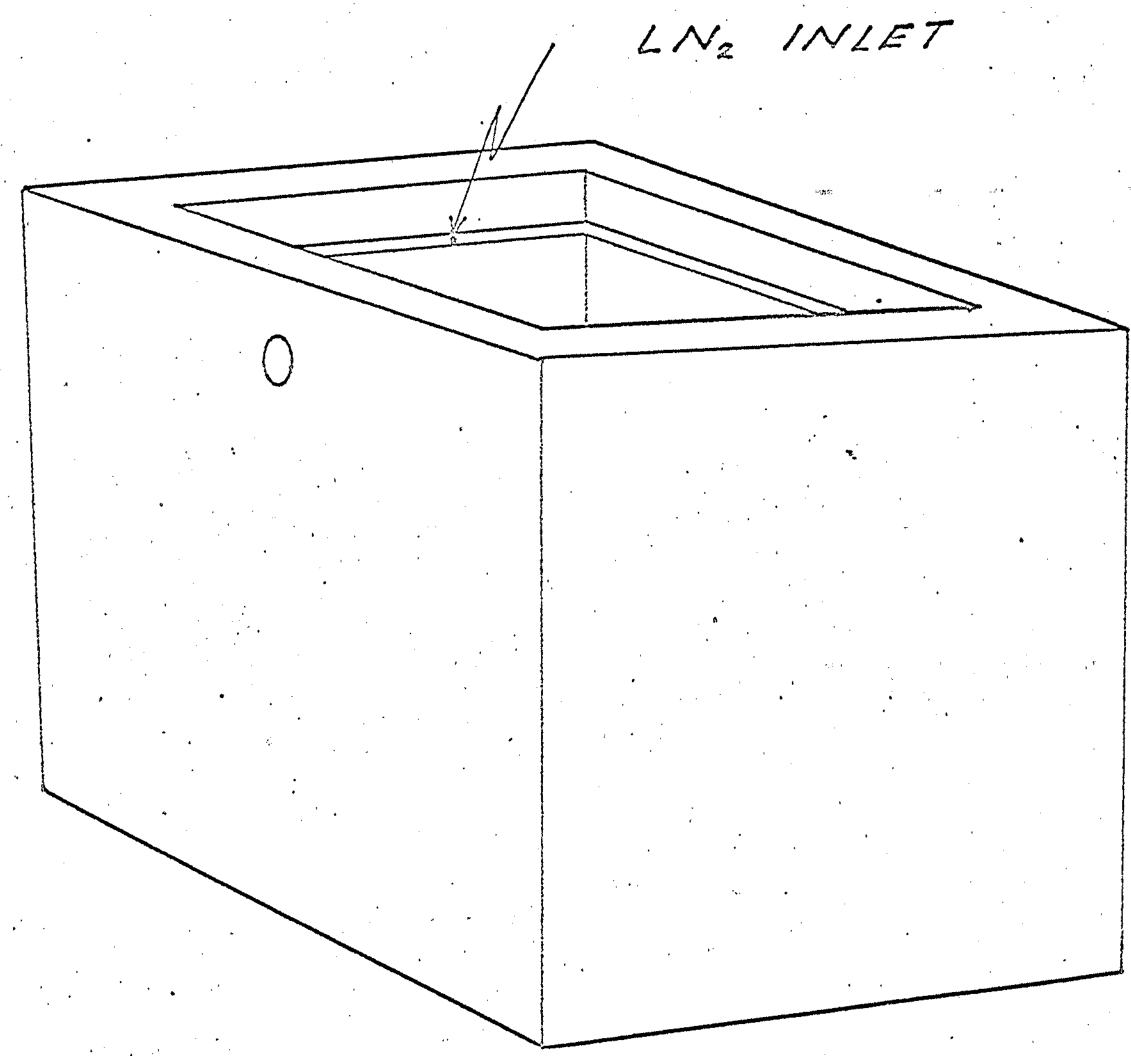

FIGURE I

VIEW OF CRYOGENIC BOX

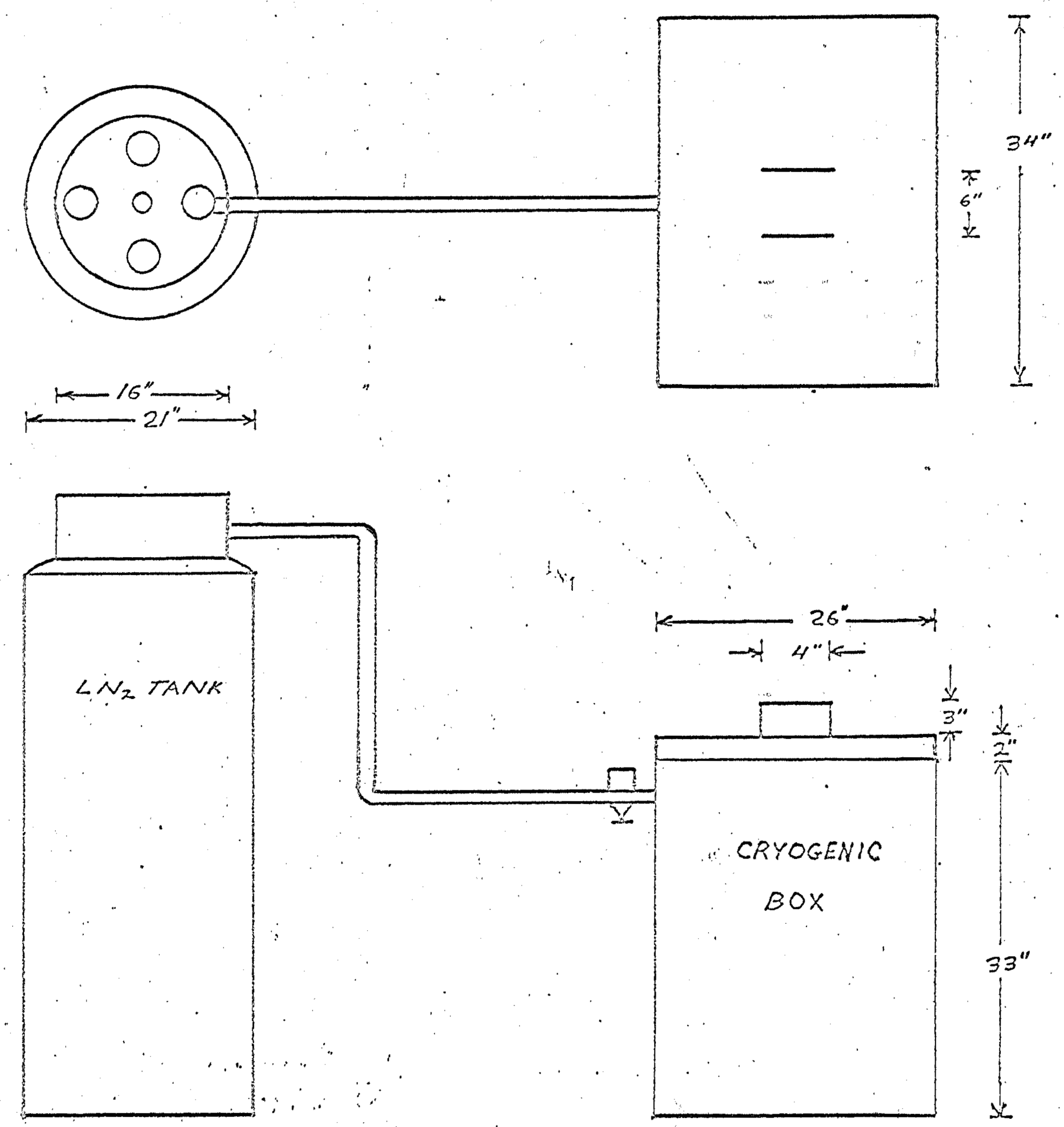

FIGURE № 2
LN_2 REFRIGERATION SYSTEM

Upon completion of the mounting of the unit aboard the J-boat, test runs were carried out in order to test the system for safety, and to check out the shrimping gear for ease of operation.

Thermocouples, which were connected to a 6 channel amplifier-recorder, were placed at various locations throughout the empty box at dockside to monitor temperatures reached at each of these locations. One thermocouple was placed outside the box to monitor ambient temperature. The amount of LN_2 used in a given time interval was determined by placing the tank on a platform scale, and recording the weight difference. The parameters of the empty box are shown in Table 2.

Trawling for shrimp was begun June 5, 1969, and was conducted in the off-shore shrimping grounds of Lake Borgne, and in an area of the Pearl River immediately north of its mouth.

As soon as the nets were emptied onto the deck of the boat, the shrimp (Penaeus setiferus and Penaeus duoarum) were culled from the trash fish, washed with sea water, and were immediately placed into stainless steel baskets in the refrigeration box where they were cooled down to, and maintained at a temperature of 28°-32°F.

Initially, the shrimp caught were very small in size, and were not truly representative of shrimp sold in retail markets, but by the second week of July, they had reached sufficient size as to be comparable to that product which reaches the consumer.

At this time, the thermocouples were again placed in the box at the same locations as before, and tests were conducted over a 48 hour period to determine temperatures at these locations in the box with 100 pounds of freshly caught, deheaded shrimp. Liquid nitrogen usage was again recorded (Table 3). As a control, an equal quantity of shrimp was stored in ice for

TABLE 2

PARAMETERS RECORDED WITH BOX EMPTY

Load in Box (lbs.)	Temperature of Thermocouples 4&5 (°F.) a/		Operating Pressure (psi)	Temperature Controller b/		Average time Solenoid Open (sec.)	LN_2 Consumption lbs./hr.
	Min.	Max.		Setting (°F)	Location from bottom (in.)		
0	30	35	20	30	23	113	14
0	29	32	40	30	23	47	10
0	28	32	50	30	23	35	9.5
0	7	27	20	30	9	155	16
0	0	25	40	30	9	60	14
0	-3	25	50	30	9	50	13

a/ Thermocouples 4 and 5 were located in areas of the box which would contain shrimp when loaded

b/ Ambient temperature ranged from 80-85° F. when tests were conducted

TABLE 3

TEMPERATURES AT VARIOUS LOCATIONS IN BOX CONTAINING 100 POUNDS SHRIMP a/

Thermocouple Number b/	Temperature (°F.)													
	Hours after Placing 100 Lbs. Shrimp into Box													
	0.1		0.5		1		5		12		24		48	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
1	-320	72	-320	-200	-320	-95	-320	-95	-320	-95	-320	-95	-320	-95
2	-320	72	-320	-20	-265	20	-265	20	-265	20	-265	20	-265	20
3	-320	72	-320	-20	-265	20	-265	20	-265	20	-265	20	-265	20
4	60	83	25	35	25	30	25	30	25	30	25	30	25	30
5	65	83	35	45	28	30	28	30	28	30	28	30	28	30
6	72	72	70	70	72	72	70	70	85	85	72	72	69	69

a/ Operating pressure--50 psi.; Temperature controller set at 30°F. and located 23 in. from bottom of box; LN_2 consumption--6 lbs. per hour; Initial temperature of shrimp--83°F.

b/ Location of thermocouples are as follows:
#1 Inlet side of solenoid valve
#2 Left outlet inside box
#3 Right outlet inside box
#4 Center and 20 in. from bottom of box
#5 Center and 9 in. from bottom of box (buried in center layer of shrimp)
#6 Ambient temperature (outside box)

the same period of time. At the end of the 48 hours, samples from three different areas of the LN_2 box were analyzed for total plate count, total coliforms, fecal E. coli and coagulase positive Staphylococcus aureus. Samples from three locations in the ice were also analyzed for the above, and the results were compared with those of the LN_2 refrigerated samples (Table 4).

TABLE 4

MICROBIOLOGICAL COMPARISONS BETWEEN SHRIMP MAINTAINED AT 28°-32°F. BY ICE STORAGE AND LN_2 REFRIGERATION

Microbiological Criterion	Method of Storage					
	Ice			LN_2		
	Sample number a/					
	1	2	3	4	5	6
Standard (total) plate count b/	8.0	8.5	13.0	3.8	2.1	3.1
Total coliforms	c/	---	----	---	---	---
Fecal *E. coli*	---	---	----	---	---	---
Coagulase positive *Staph. aureus*	---	---	----	---	---	---

a/ Sample 1 taken from top layer of shrimp
Sample 2 taken from center layer of shrimp
Sample 3 taken from bottom layer of shrimp
Sample 4 taken from upper portion of box
Sample 5 taken from center portion of box
Sample 6 taken from bottom portion of box

b/ Counts expressed X 10^3 organisms/gram shrimp

c/ Indicates none present

RESULTS AND DISCUSSION

It was apparent from the data in Table 2 that the following conditions be met in order to obtain maximum efficiency for the system:

1. Operating pressure--50 psi.
2. Temperature sensing probe location inside box-23 in. above bottom center of box.
3. Setting of temperature controller--30°F.

These conditions were determined to be ideal since the temperature inside the box was maintained at 28°-32°F., which is slightly above the freezing point of shrimp (28°F.). Under these conditions, the LN_2 consumption proved to be lower than with any other combination. It is quite likely that the positioning of the temperature sensing probe is the most critical adjustment of the three, since temperatures had a wide variation, and tended to reach extremely low minimums when it was placed low in the box (9 in. from the bottom).

Table 2 shows temperatures at various locations in the box containing 100 pounds shrimp. Initially the box temperature and ambient temperature were the same, however, within 5 minutes after the solenoid valve opened and introduced the LN_2 into the box, the temperatures measured by thermocouples 4 and 5 showed substantial drops in temperature. After 30 minutes, the temperature in the center of the layer (thermocouple 5) had dropped to near freezing, while the temperature of thermocouple 4 located approximately 1 in. above the top layer of shrimp registered slightly below the freezing point of shrimp.

At one hour, the temperature measured at the box outlets registered higher than had been previously noted. This was due to the "flashing" of LN_2 which occurred intermittently during the test. When the LN_2 flashed through the outlets, these thermocouples read -320°F., but at other times when only gas was being emitted, a reading of -265°F. was noted.

Temperature equilibrium was reached between 30 minutes and 1 hour after the test was begun. This was determined by the stability of readings from thermocouples 4 and 5 by the time 1 hour had elapsed.

The microbiological studies showed SPC (standard plate count) numbers to be definitely higher in the shrimp stored in ice than in the LN_2 refrigerated shrimp. The lowest count (8.5×10^3) obtained with the ice stored samples was considerably higher than the highest count found with the LN_2 samples (3.8×10^3). It is also interesting to note that those samples of shrimp stored in the upper layer of shrimp had lower SPC counts than did those in the bottom layers. Total coliforms, fecal *E. coli*, and coagulase positive *Staph. aureus* were not found in the shrimp tested.

LITERATURE CITED

1. Fieger, E. A., Green, M., Lewis, H., Holmes, D., and Dubois, C. W. Shrimp handling and preservation. Refrig. Eng., 58, 244 (1950).

2. Green, Margaret. Bacteriology of shrimp. II. Quantative studies of freshly caught and iced shrimp. Food Research, 14, 372 (1949).

3. Novak, A. F., Rao, M. R., and Brown, D. C. Use of liquid nitrogen for shellfish preservation. Chemical Engineering Progress Symposium Series, 62, 73 (1966).